*Astrophysical Dynamics: From Galaxies to Stars*
*Proceedings IAU Symposium No. 271, 2010*
*N.H. Brummell & A.S. Brun*

DOI: 00.0000/X000000000000000X

# Convection and dynamo action in B stars

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**Abstract.** Main-sequence massive stars possess convective cores that likely harbor strong dynamo action. To assess the role of core convection in building magnetic fields within these stars, we employ the 3-D anelastic spherical harmonic (ASH) code to model turbulent dynamics within a 10 $M_\odot$ main-sequence (MS) B-type star rotating at 4 $\Omega_\odot$. We find that strong (900 kG) magnetic fields arise within the turbulence of the core and penetrate into the stably stratified radiative zone. These fields exhibit complex, time-dependent behavior including reversals in magnetic polarity and shifts between which hemisphere dominates the total magnetic energy.

**Keywords.** stars: early type, rotation, magnetic fields

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Surface magnetic fields have been found on many MS massive stars (e.g. Donati & Landstreet 2009). To some degree both the fossil fields and dynamo generated fields in these stars must coexist, although how they interact to produce and maintain these surface fields is unclear. Recent work has shed some light on the interaction between a super-equipartition core dynamo and fossil magnetic fields in A-type stars (Brun et al. 2005, Featherstone et al. 2009). We extend this work to a much more luminous 10 $M_\odot$ star with a rotation period of seven days (4 $\Omega_\odot$) which is typical for active MS B stars.

Using the 3-D ASH code, we study convection and dynamo action realized in the core and part of the surrounding radiative envelope of this 7200 $L_\odot$ B star. ASH is a mature modeling tool which solves the anelastic MHD equations of motion in a rotating spherical shell using a pseudo-spectral method (e.g. Brun et al. 2004). The mean structure in this ZAMS star is obtained from a stellar evolution code. We capture the full spherical geometry with a radial domain that occupies 0.6 $R_*$ (covering 7 pressure scale heights), with the inner 0.2 $R_*$ being convectively unstable. The innermost 0.02 $R_*$ is excluded to avoid the coordinate singularity at the origin in the ASH code. The upper and lower radial boundary conditions are stress-free and impenetrable for the velocity field and perfect conductor (lower) and potential field (upper) for the magnetic field.

The intricate and time-varying flows established in this simulation are largely aligned with the rotation axis. These columnar convection cells break the spherical symmetry due to equator-crossing meridional circulations and a north-south asymmetric differential rotation. A central columnar flow (occupying the inner 0.1 $R_*$ at the equator) stretches north-south across the entire core, rotates retrograde to the reference frame, and gently flares out to about 25° in latitude at the core boundary (Fig. 1a). Along the rotation axis within this column are strong vortical flows. Outside the central column, there are typically five columnar convection cells that rotate prograde to the reference frame. These cells transport angular momentum between the central column and the overshooting region, where there is a weak prograde equatorial flow. These flows maintain a mean rotation rate that increases monotonically from the center of the star to become nearly uniform within the radiative envelope, with an overall radial differential rotation of 25%.

A strong dynamo operates within the core, generating magnetic fields with peak strengths reaching 900 kG (200 kG rms). These fields form equatorward tilted strands

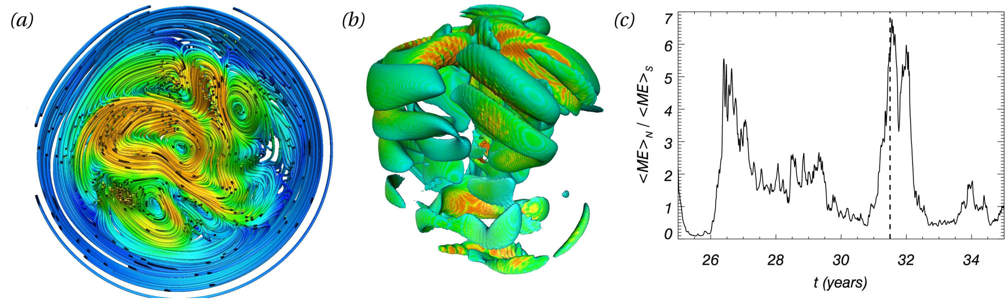


**Figure 1.** (a) Velocity streamlines within the core, cut along the equator. Fast core-crossing flows and several columnar flows are visible. Orange tones indicate fast flow speeds ($|v| > 300\,\mathrm{m\,s^{-1}}$, peak 1000 $\mathrm{m\,s^{-1}}$), slower speeds in blue tones. (b) An isocontour rendering of magnetic energy showing the dominance of the northern hemisphere and equatorward tilted magnetic structures (rotation axis vertical). (c) North to south ratio of hemispherical averages of ME shown for a decade of time evolution; (a) and (b) are rendered at 31.5 years (dashed line).

that encircle the core (Fig. 1b). The fluctuating component of the magnetic field comprises 76% of the total magnetic energy (ME) in the core, while 21% remains in the mean toroidal field and 3% in the mean poloidal field. On average the total ME is 55% of the convective kinetic energy, but there are intervals where it approaches 86% indicating that the ME is nearing equipartition.

The time evolution of magnetic field is complex and multi-periodic. When averaged over several decades, the ME of the northern hemisphere is 1.7 times greater than that of the southern hemisphere. There are intervals, however, when the southern hemisphere comes to dominate the magnetic energy (Fig. 1c), but only by a factor of at most 2.5. The northern hemisphere, on the other hand, dominates the ME for periods of up to two years by a factor as great as 6.7. These magnetic field configurations have quadrupolar and dipolar components that are nearly equal and opposite, which have been shown to exist when there is weak equatorial symmetry breaking (Gallet & Pétrélis 2009).

The greatest extent of convective overshooting into the stable radiative envelope occurs at mid-latitudes. The sustained overshooting pushes magnetic field and lower entropy fluid into the stable layer, making the core prolate and stochastically exciting gravity waves. The strongest magnetic fields (900 kG) and fastest flows ($1\,\mathrm{km\,s^{-1}}$) typically occur along the edge of the central column and are maximum where this column transects the core boundary. As this field is advected into the overshooting region it is combed into a large-scale toroidal field ($\sim$30 kG) by the flows in the stable region. Therefore, in this region, the velocity and magnetic fields are nearly aligned creating a force-free state.

To better understand the hemispherical dynamo state achieved within this B-star model, simulations at varying rotation rates and lower diffusivities must be run. Minimal diffusion is especially important if we are to capture the buoyant magnetic structures that likely arise from the strongest fields in these models.

This work was supported by NASA grants NNX08AI57G and NNX10AM74H and by NSF Teragrid supercomputing resource grant TG-MCA93S005.

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